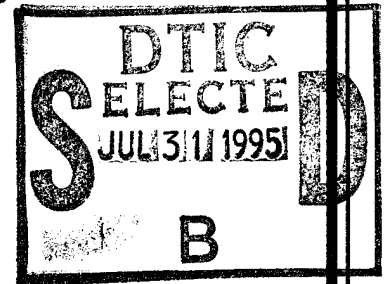


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**RELATIONSHIP BETWEEN AGE AND SUSCEPTIBILITY
TO DECOMPRESSION SICKNESS: A REVIEW**

**Zahid M. Sulaiman, 2LT, USAF, BSC
Andrew A. Pilmanis
Robert B. O'Connor, Capt, USAF, BSC
F. Wesley Baumgardner**



**CREW SYSTEMS DIRECTORATE
Crew Technology Division
2504 Gillingham Drive, Suite 1
Brooks Air Force Base, TX 78235-5104**

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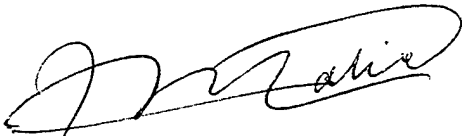
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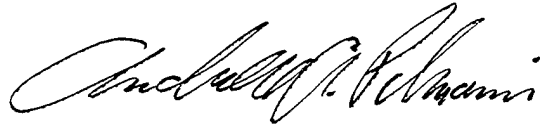
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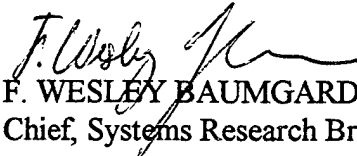
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ZAHID M. SULAIMAN, 2Lt, USAF, BSC
Biomedical Engineer



ANDREW A. PILMANIS, PhD
Chief, High Altitude Protection



F. WESLEY BAUMGARDNER, PhD
Chief, Systems Research Branch



JAMES P. DIXON, Colonel, USAF, BSC
Chief, Crew Technology Division

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13. ABSTRACT (Maximum 200 words) Susceptibility to decompression sickness (DCS) is influenced by a multitude of factors. The purpose of this study was to determine the effect of age on susceptibility to DCS. A review of the literature on the relationship between age and susceptibility to DCS found an appreciable effect of age on group and individual susceptibility. Most of the studies reviewed were done during World War II and were limited to the age group between 18 and 30. However, Armstrong Laboratory (AL) DCS research database does include data for subjects over 40 years of age. The results from the AL DCS research database show that there was a significant increase in DCS risk for subjects over 42 years of age. They also show that susceptibility to DCS increases with age. There is generally a linear relationship between increasing age and increasing individual susceptibility to DCS..				
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TABLE OF CONTENTS

	Page
Introduction	1
Susceptibility	1
Relationship between age and susceptibility to DCS	2
Summary	7
References	10

LIST OF FIGURES

1. Susceptibility to decompression sickness related to age	4
2. Relation of bends to age	5
3. Susceptibility to DCS vs. age	6
4. Susceptibility to DCS vs. age (Altitude > 20K feet)	8
5. Susceptibility to DCS vs. age (Altitude = 29.5 K - 30 K feet)	9

LIST OF TABLES

1. Susceptibility to Decompression Sickness of Various Age Groups	2
2. Age and Susceptibility to Decompression Sickness	3
3. Bends and Age	4
4. Susceptibility to DCS vs. Age	6
5. Susceptibility to DCS vs. Age for Altitude < 20,000 feet	7
6. Susceptibility to DCS vs. Age for Altitude > 20,000 feet	8
7. Susceptibility to DCS vs. Age for Altitude = 29.5K - 30K feet	9

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Relationship Between Age and Susceptibility to Decompression Sickness: A Review

Introduction

"In the period of over 100 years since the first recognition of decompression sickness (DCS), researchers in the field have asserted that age has an adverse effect on tolerance to altitude" (8). An extensive literature search on the relationship between age and susceptibility to DCS was conducted using databases from the Armstrong Laboratory (AL) DCS literature (DCSREF), the National Technical Information Service (NTIS), the Defense Technical Information Center (DTIC), Aerospace Medline, the Underwater Medicine Bibliography and several classical texts. The literature discussing the relationship between age and susceptibility to decompression sickness on both aviators and divers was reviewed.

According to Gray (12), certain individuals, when exposed repeatedly to a standard pattern of decompression, frequently develop DCS symptoms, whereas other individuals under the same conditions rarely do so, which indicates the existence of individual differences in susceptibility to decompression sickness. A given individual, when exposed repeatedly to a standard pattern of decompression may develop symptoms on some occasions, but not on others, indicating the existence of intra-subject variations in susceptibility to DCS.

Many authors have pointed out the variation in susceptibility between different individuals and have attempted to correlate this variability with age, weight or other physiological characteristics (8, 29, 31). Some authors have also pointed out that there may be considerable variation in the occurrence and severity of decompression sickness in the same individual at different times, and that this variability may be related to exercise (4, 6, 11, 17, 26), altitude of residence (7) and temperature (8, 13, 21, 33). Thus, there are a number of factors which may increase the susceptibility of an individual to DCS. The purpose of this report is to review age as one of the factors affecting susceptibility to DCS.

Stewart et al. (28, 29), have shown that the susceptibility of one individual to decompression sickness may be very different from that of another, presumably because of some difference in the physiology of the two individuals. Susceptibility to decompression sickness is undoubtedly influenced by a multitude of factors. This multiplicity of simultaneously operating factors tends to obscure the influence of any one factor. In such a situation, Gray (12) noted that the statistical methods of multiple and partial correlation are almost essential. The occurrence and severity of decompression sickness in a single individual may also be different on separate exposures, either because of changes in the environment or changes within the body itself not directly referable to environmental changes.

Susceptibility

The susceptibility of a given subject at a given moment may be determined by exposing the subject at that moment to a standard decompression. The presence of symptoms indicates susceptibility, and the absence of symptoms, nonsusceptibility. The only direct and reliable measure of an individual's susceptibility consists of determining the percentage of a large number of repeated standard decompressions in which the individual develops symptoms.

A more relevant procedure than the above is the measurement of group susceptibility. This metric may be accomplished directly and quantitatively by determining the percentage of a large number of subjects who develop symptoms during a single standard decompression. There are two important characteristics of this measurement of group susceptibility. First, it is reliable in the sense that a repetition of the measurement on a given very large group will yield only random variation within rather narrow limits. Second, it is numerically equivalent to the mean of the individual susceptibilities of the subjects composing the large group.

Relationship Between Age and Susceptibility to DCS

Fryer (9) noted that a man of any age may be a good or a bad subject in the decompression chamber, but there is a very distinct relationship between age and susceptibility to decompression sickness in the population. He states that susceptibility to decompression sickness increases by nine-fold between the age groups 17-20 and 27-29 years. He pointed out that there is no good statistical evidence on older men, or on women of any age, but it is generally accepted that susceptibility continues to increase with advancing age.

Ever since Pol and Watelle (22) reported the first systematic study of caisson disease in 1854, age has been considered as a "potential" factor affecting susceptibility to decompression sickness. Catsaras (3), Snell (27) and von Schrotter (13) have presented figures implying a higher incidence of compressed air illness in older than in younger workers. This opinion was supported by studies on experimental compressed air illness reported by Hill et al (15) and Boycott et al (2). In the hypobaric field, previous reports (5, 9, 12, 19, 20, 28, 32) have concluded that there is an increased susceptibility to decompression sickness in older men. In 1944, Thompson (32) presented data on the relationship of decompression sickness susceptibility to age. The incidence of decompression sickness according to age groups from Thompson (32) is in Table 1, which shows the susceptibility to DCS for 1,347 men who had one to three runs in a low pressure chamber. Individuals experiencing any symptoms of DCS, regardless of severity, on one or more occasions were termed "susceptible." The study showed a linear relationship between age and susceptibility to decompression sickness.

**Table 1. Susceptibility to Decompression Sickness
of Various Aircrew Age Groups (Thompson, 1944)**

Age in Years	Susceptible to Decompression Sickness		Not Susceptible to Decompression Sickness		Total
	# of Subjects	Percent	# of Subjects	Percent	
18 to 19	65	50.00	65	50.00	130
20 to 21	204	55.28	165	44.72	369
22 to 23	187	57.72	137	42.28	324
24 to 25	123	61.19	78	38.81	201
26 to 27	75	58.14	54	41.86	129
28 to 29	60	62.50	36	37.50	96
30 to 31	35	74.47	12	25.53	47
32 to 33	28	70.00	12	30.00	40
34 to 35	11	100.00	0	0.00	11
Total	788		559		1347

Gray (12) made extensive observations on the incidence of altitude decompression sickness in U.S. Army Air Corps trainees of various ages, chiefly from 18 to 28, during World War II. The results, shown in Table 2, uniformly reveal an increase in group susceptibility with

increase in age. The data are from a total of 52,313 subjects reported by six independent sources (1, 12, 20, 24, 29, 32). Although the effect of age is apparent in each of the above sets of data, it is difficult to compare one set with another because the mean age varies from 21.7 to 24.6 years and the mean incidence of severe symptoms varies from 4.24 to 28.4 percent. Also, the altitude and duration of flight vary from one set to another.

Table 2. Age and Susceptibility to Decompression Sickness (Gray, 1951)

Source	Flight Pattern	Age		Number of Subjects	Severe Symptoms		
		Mean	Range		No.	%	Relative Susceptibility
R.C.A.F	35,000 feet for 4 hr	19.5	18-20	59	7	11.9	53
		22.5	21-23	78	17	21.8	96
		25.5	24-26	43	14	32.6	144
		28.5	27-29	18	7	38.9	171
	Totals and means	22.9		198	45	22.7	100
Randolph Field	3 hours at 38,000 feet	20.9	18-21	87	18	20.7	83
		22.5	22	93	23	24.7	99
		23.5	23	105	27	25.7	103
		25.0	24-25	222	63	28.4	113
	Totals and means	24.6		660	187	28.4	114
Pensacola	35,000 feet for 40 min, then 40,000 ft for 10 min.	21.6	19-22	455	23	5.06	61
		24.0	23-24	312	27	8.65	105
		26.0	25-26	179	38	15.50	188
	Totals and means	23.2		946	88	8.25	100
Kingman Field	3 hours at 38,000 feet	19.4	17.5-20.5	1266	45	3.55	61
		21.5	20.5-22.5	969	46	4.75	81
		25.0	22.5-28.5	932	67	7.19	123
	Totals and means	21.7		3167	158	4.99	85
Santa Ana	3 hours at 38,000 feet	20.8	19-21	1097	89	8.11	72
		22.9	22-23	987	118	11.96	106
		25.0	24-25	579	74	12.78	113
	Totals and means	23.2		3170	357	11.26	100
Maxwell Field	1 hour at 30,000 feet, and 15 min. at 38,000 feet	19.3	18-19	11,718	387	3.30	72
		21.0	20-21	15,472	612	3.96	86
		23.3	22-24	10,672	539	5.05	110
		26.7	25-30	6310	334	5.29	115
	Totals and means	22.0		44,172	1872	4.24	93

In Figure 1, relative susceptibility is plotted against age for each of the six sets of data. The 23 points describe a reasonably straight line. From this linear relationship, Gray (12) developed an equation to determine relative susceptibility to DCS with respect to age.

$$\text{Relative susceptibility} = 10.8 (\text{age}) - 145.$$

This regression equation reveals that the relative susceptibility increases by 10.8 % points for each year increase in age, over the range of 18 to 28 years. These results suggest an appreciable effect of age on group susceptibility to altitude decompression sickness.

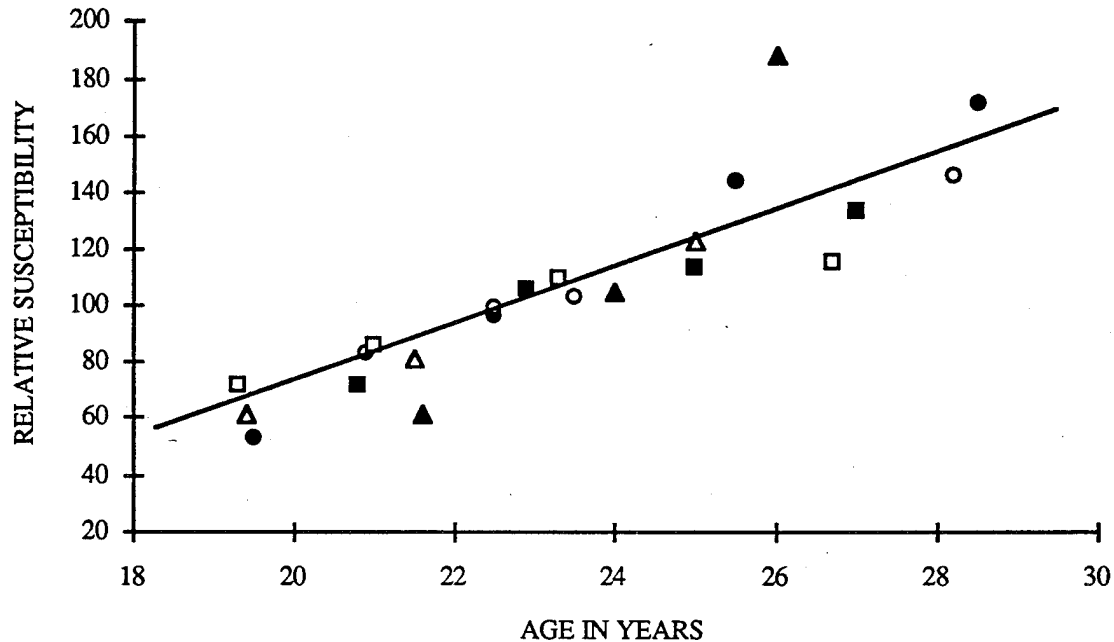


Figure 1. Susceptibility to decompression sickness related to age (Gray, 1951)

Motley, Chinn and Odell (20) found a much less striking variation with age, as illustrated in Table 3. They studied 68,422 trainees, and found over 9,500 cases of bends. The difference in percentage of bends between ages 18 and 29 was only 4%. The percentage in those age 30 actually dropped to 5.2%, as compared with 9.4% for age 18. However, the number of subjects in the 30-year age group was very small compared to that for 18. When data for all subjects over age 30 were analyzed, the percentage of bends rose to 20.1%.

Table 3. Bends and Age (Motley, 1945)

Age	Number of Subjects	Percentage of Bends						Total	Bearable/Unbearable
		Grade I	Grade II	Grade III	Grade IV	Bearable (1 & 2)	Unbearable (3 & 4)		
18	2355	2.3	4.6	2.3	0.2	6.9	2.5	9.4	2.8
19	9363	2.7	5.8	2.9	0.6	8.5	3.5	12.0	2.4
20	8250	3.5	6.3	3.5	0.5	9.5	4.0	13.8	2.5
21	7222	2.8	5.8	3.5	0.4	8.6	3.9	12.5	2.2
22	4736	2.7	6.7	4.3	0.6	9.4	4.9	14.3	1.9
23	3580	2.3	5.8	4.3	0.6	8.1	4.9	13.0	1.6
24	2356	2.4	6.3	4.7	0.9	8.7	5.6	14.3	1.6
25	2229	2.5	7.6	5.1	0.7	10.1	5.8	15.9	1.7
26	2081	2.3	7.1	4.6	0.5	9.4	5.1	14.5	1.8
27	1571	2.7	7.9	3.9	0.8	10.6	4.7	15.3	2.3
28	155	3.2	3.9	3.2	2.5	7.1	5.7	12.8	1.2
29	59	3.3	6.7	1.7	1.7	10.0	3.4	13.4	2.9
30	74	1.0	2.1	2.1	0	3.1	2.1	5.2	1.5
Over 30	141	4.2	7.6	6.9	1.4	11.8	8.3	20.1	1.4

Reports from other authors (5, 9, 12, 32) show two to six times as many bends in men aged 25 - 27 as in those 18 - 19 years of age, although a linear increase in susceptibility to DCS

among the age group 18 - 25 was observed. However, the differences were far less than those reported by other authors (5, 9, 12, 32). An interesting observation was the disproportionate rise of the more severe bends among older men, as shown in Figure 2. The ratio of bearable to unbearable bends falls from 2.5 in the youngest to 1.5 in the oldest group.

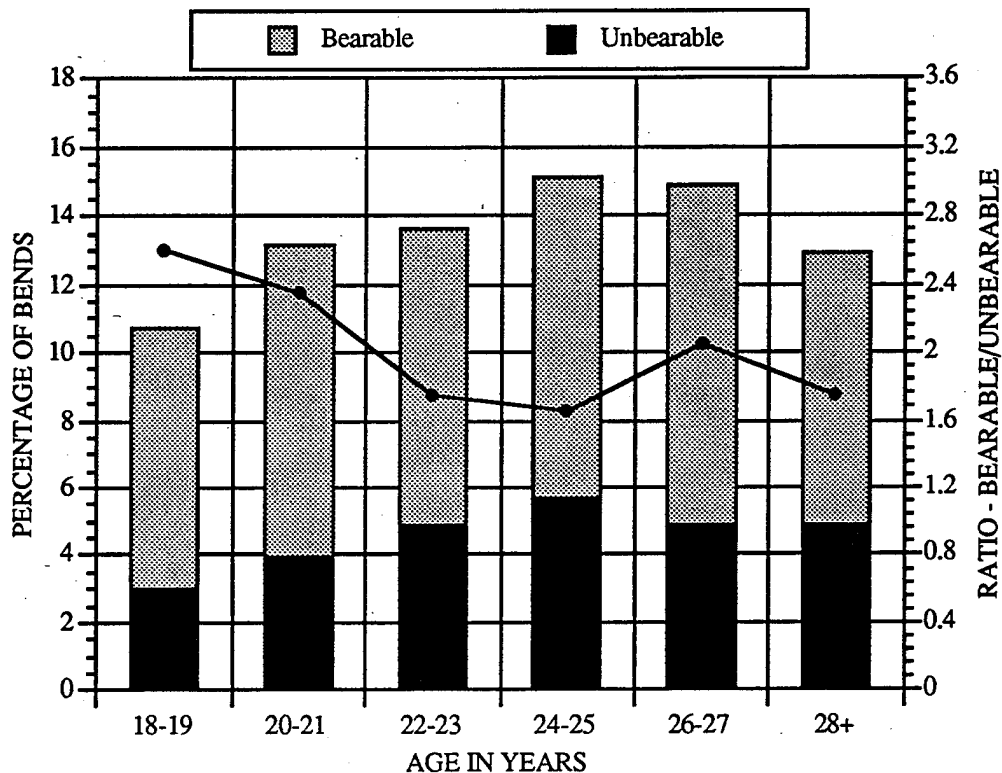


Figure 2. Relation of Bends to Age (Motley, 1945)

The majority of studies discussed thus far were conducted during World War II or shortly thereafter. More recent studies by Lo and O'Kelly (18), Smead et al. (25) and Webb et al. (34) also concluded that increasing age increases susceptibility to DCS. However, Kumar et al. (16) found no significant effect of age on susceptibility to DCS. Furthermore, all of these studies used a small number of subjects and were not originally designed to investigate age as a factor in DCS susceptibility. Therefore, the findings reported should be generalized with caution.

In this study we also examined our own Armstrong Laboratory (AL) DCS Research Database for a relationship between age and susceptibility to decompression sickness. Table 4. and Figure 3. contain data on 1,299 subjects exposed between October 1983 to March 1994 for 4 to 8 hours at various altitudes in a hypobaric chamber. Individuals experiencing any symptoms of decompression sickness, regardless of severity, on one or more occasions are termed 'susceptible'. The results show an increasing susceptibility to decompression sickness with age approximately of the order of three-fold comparing the age groups 18-21 with over 42 years of age. The results show that there is a significant increase in DCS risk for subjects over 42 years of age than among younger age groups (chi-square= 36.1, $P < .001$). In contrast to data cited earlier, an interesting observation is that there is no major change in susceptibility to DCS for age groups from 26 through 41 years.

Table 4. Susceptibility to DCS Versus Age*

AGE GROUPS	Susceptible to Decompression Sickness		Not Susceptible to Decompression Sickness		TOTAL
	# of Subjects	Percent	# of Subjects	Percent	
18-21	28	23.53	91	76.47	119
22-25	71	24.74	216	75.26	287
26-29	135	37.60	224	62.40	359
30-33	89	37.24	150	62.76	239
34-37	55	37.93	90	62.07	145
38-41	42	38.18	68	61.82	110
> 42	25	62.50	15	37.50	40
Total	445		854		1299

* from Armstrong Laboratory DCS Research Database (1983-1994).

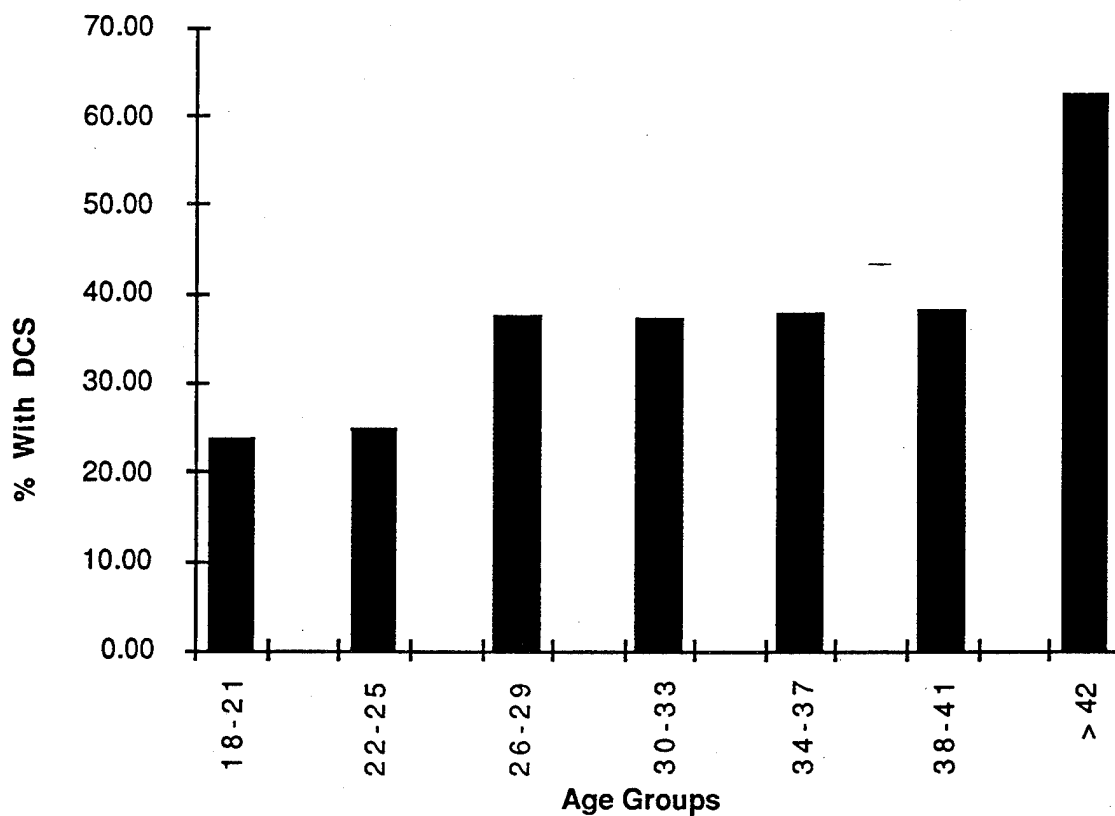


Figure 3. Susceptibility to DCS of various age group

To determine if the differences in susceptibility between the youngest and oldest age groups could be a function of their exposure altitude, the data from the AL DCS Research Database were analyzed by age group for exposures above and below 20,000 feet. Table 5. shows data from 420 subjects whose exposures were less than 20,000 feet.

Table 5. Susceptibility to DCS Vs Age (Altitude < 20,000 feet)*

AGE GROUPS	Susceptible to Decompression Sickness		Not Susceptible to Decompression Sickness		TOTAL
	# of Subjects	Percent	# of Subjects	Percent	
18-21	1	2.17	45	97.83	46
22-25	1	0.93	107	99.07	108
26-29	1	0.94	105	99.06	106
30-33	2	2.63	74	97.37	76
34-37	0	0.00	41	100.00	41
38-41	1	3.85	25	96.15	26
> 42	2	11.76	15	88.24	17
Total	8		412		420

Table 6 and Figure 4 show the incidence of decompression sickness on 880 subjects who were exposed to altitude greater than 20,000 feet for 4 to 8 hour and prebreathed from 0 to 2 hours and 15 minute. Figure 4. show an identical trend, that there is a significantly increased susceptibility to DCS risk among those over 42 years of age compared with those in much younger age groups (chi-square= 32.6, $P < 0.001$). It also show that there is approximately of the order of three-fold increase in susceptibility to DCS between the age group 18-21 with over 42 years of age. Again, there is no major change in susceptibility to DCS for the age groups between 26 to 41 years.

We also separately analyzed a subset of data on 111 subjects who had been exposed to an altitude of 29,500 - 30,000 feet. Prior to exposure, they all prebreathed 100% oxygen for one hour. Subjects completed at least 4 hours at simulated altitude, during which time they performed light to moderate exercise. These results, illustrated in Figure 5. and Table7, also show that there is a greater increase in susceptibility to DCS among those over 42 years of age than those in younger age groups.

Summary

Decompression sickness affects some people more frequently than others. Group susceptibility also varies from time to time. A review of the literature on the relationship between age and susceptibility to DCS found an appreciable effect of age on group and individual susceptibility. There are other constitutional factors that are involved in the incidence of decompression sickness, such as time of day, atmospheric condition, exercise, fluid intake, weight, height and gender. However, some studies demonstrated a minimal effect of age and susceptibility to DCS. Furthermore, most of the studies reviewed were done during World War II and were limited to the age group between 18 and 30. However, the AL DCS Research Database, containing data from 1983 to 1994, does include data for subjects over 40 years of age. The results from the AL DCS Research database shows that there is a significant increase in DCS risk for subjects over 42 year of age compare to younger age group (chi-square= 36.1, $P < .001$). It also

shows that susceptibility to DCS increases with age. In conclusion, there is generally a linear relationship between increasing age and increasing individual susceptibility to DCS.

Table 6. Susceptibility to DCS vs Age (Altitude > 20,000 feet)*

AGE GROUPS	Susceptible to Decompression Sickness		Not Susceptible to Decompression Sickness		TOTAL
	# of Subjects	Percent	# of Subjects	Percent	
18 - 21	27	36.49	47	63.51	74
22 - 25	78	43.58	101	56.42	179
26 - 29	133	52.57	120	47.43	253
30 - 33	86	52.76	77	47.24	163
34 - 37	53	50.96	51	49.04	104
38 - 41	41	48.81	43	51.19	84
> 42	23	100.00	0	0.00	23
Total	441		439		880

* from Armstrong Laboratory DCS Research Database (1983-1994)

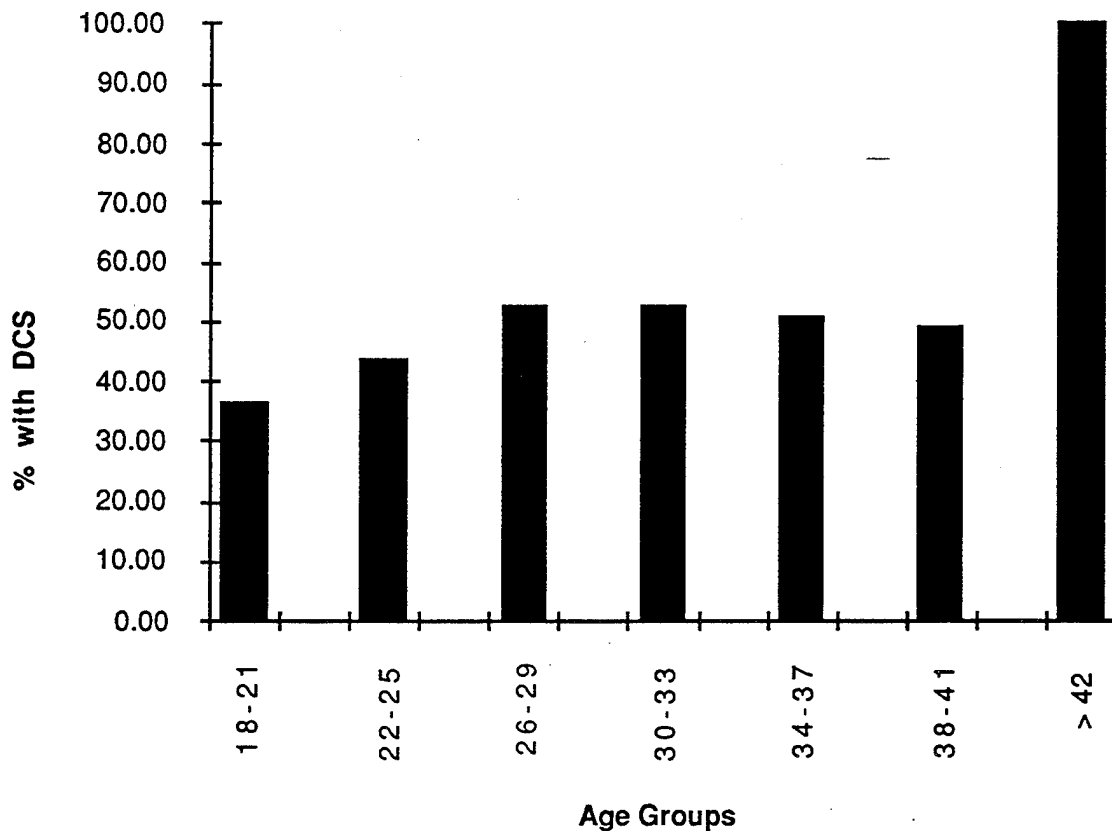


Figure 4. Susceptibility to DCS of various age group at altitude > 20,000 feet

Table 7. Susceptibility to DCS vs Age (Altitude = 29.5K - 30K feet)*

AGE GROUPS	Susceptible to Decompression Sickness		Not Susceptible to Decompression Sickness		TOTAL
	# of Subjects	Percent	# of Subjects	Percent	
18 - 21	3	30.00	7	70.00	10
22 - 25	18	52.94	16	47.06	34
26 - 29	21	65.63	11	34.38	32
30 - 33	9	64.29	5	35.71	14
34 - 37	10	90.91	1	9.09	11
38 - 41	4	57.14	3	42.86	7
> 42	3	100.00	0	0.00	3
Total	68		43		111

* from Armstrong Laboratory DCS Research Database (1983-1994)

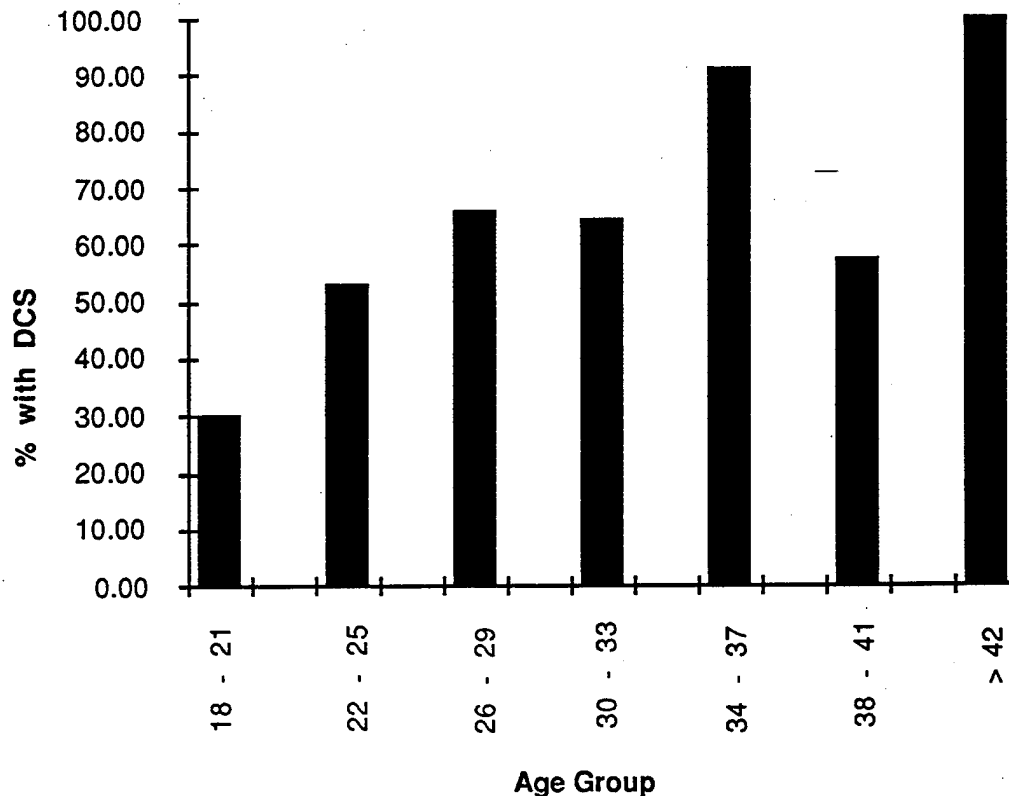


Figure 5. Susceptibility to DCS of various age group at altitude = 29.5K - 30K feet

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